A CONSORTIUM TO RAISE THE YIELD POTENTIAL OF WHEAT

Can we drive a second green revolution?

Martin Parry

Food Security: Challenge

'Demand for food is projected to increase by 50% by 2030 and double by 2050 '

http://www.bbsrc.ac.uk/organisation/policies/reviews/consultations/0905_food_security_consultation.pdf
http://news.bbc.co.uk/1/hi/in_depth/world/2008/costoffood/default.stm

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Food Security: Challenge

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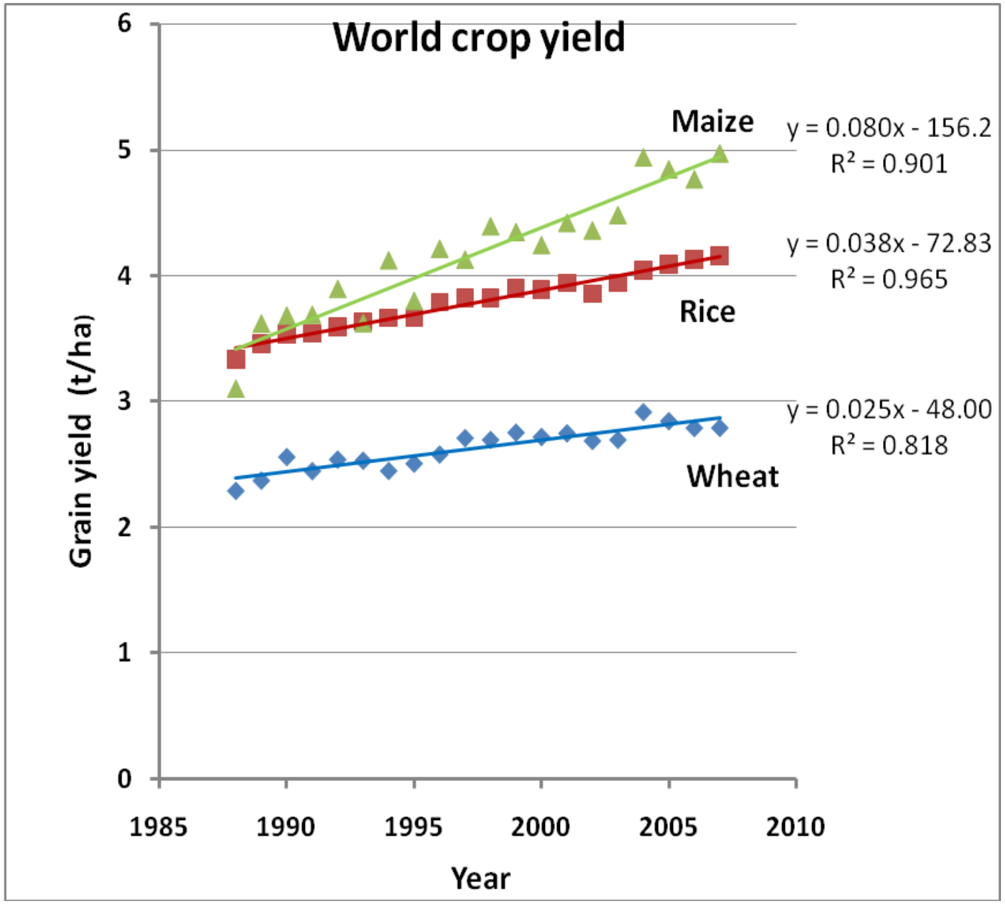
- more output
- from less land
- with less water
- with less energy
- with less emissions

Food Security: Challenge



World yields for wheat, rice and maize, 1988-2007. Source: FAOSTAT.

- **Raising genetic yield potential**

- Minimise gap between yield potential & actual yield

WYC Background

- Conceived in 2006
- Integrated activity across 3 research themes
- Seeking a £70M USD investment
- main sites
- Open Strategic collaboration
  - 6 Countries
  - 20+ universities and institutes
  - ? industrial partners

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Proposed research themes

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1) **Increasing photosynthetic capacity and efficiency**

2) **Optimizing partitioning to grain yield while maintaining lodging resistance**

3) **Breeding to accumulate yield potential traits**

Bottleneck to raising genetic yield potential

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- Photosynthetic capacity barely changed since wheat breeding began.

- Basic research suggests substantial improvements in yield are theoretically possible.
  - CO_2 enrichment experiments
  - C_4 crops (e.g. maize, Sorghum, Millet) show up to 50% greater RUE than C_3 species (wheat, rice, beans, potatoes, most vegetables)

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Total Photosynthesis

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- Interception of Radiation
- Duration of Photosynthesis
- Rate of photosynthesis
- Extent of down regulation

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Rubisco substrates

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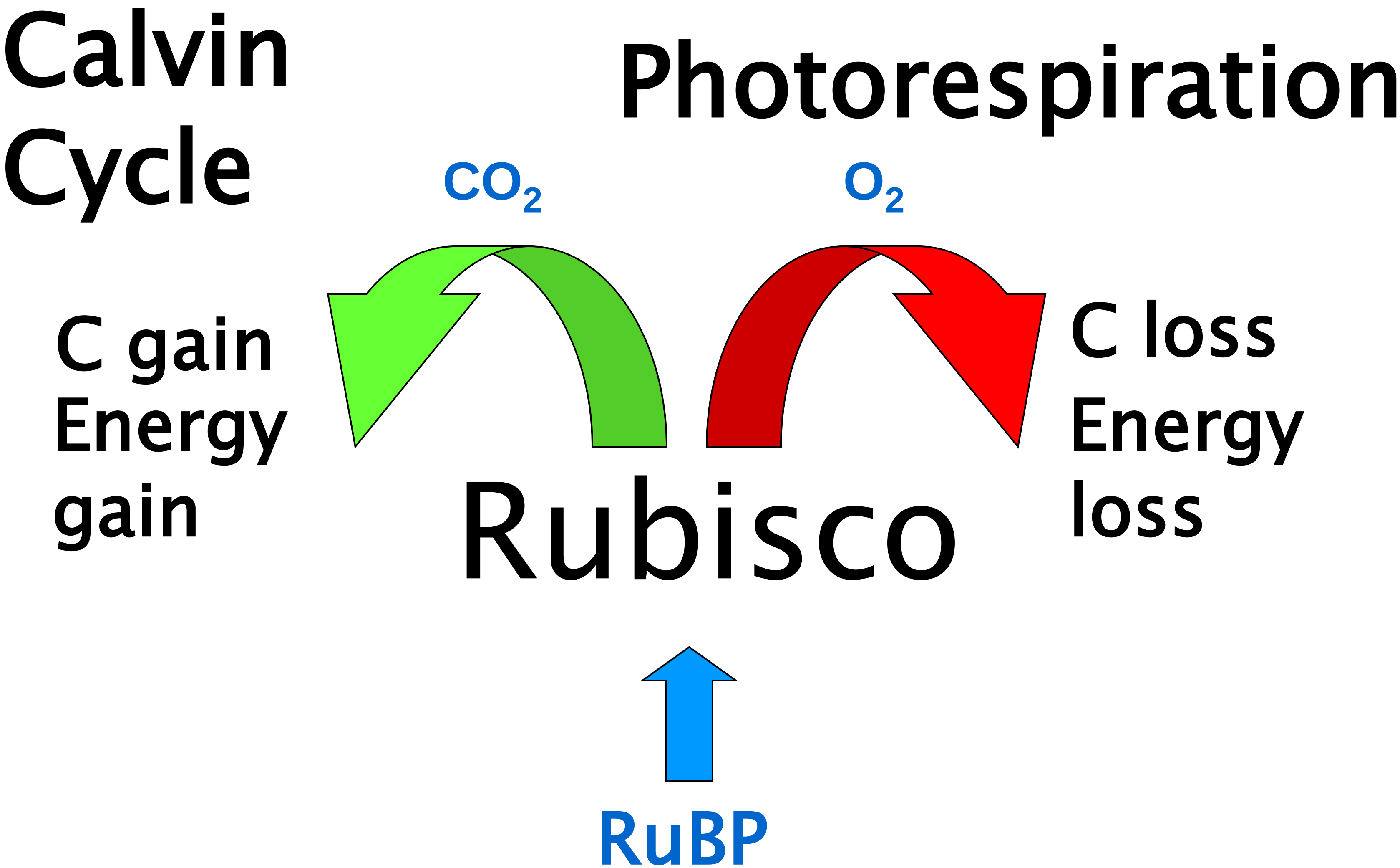
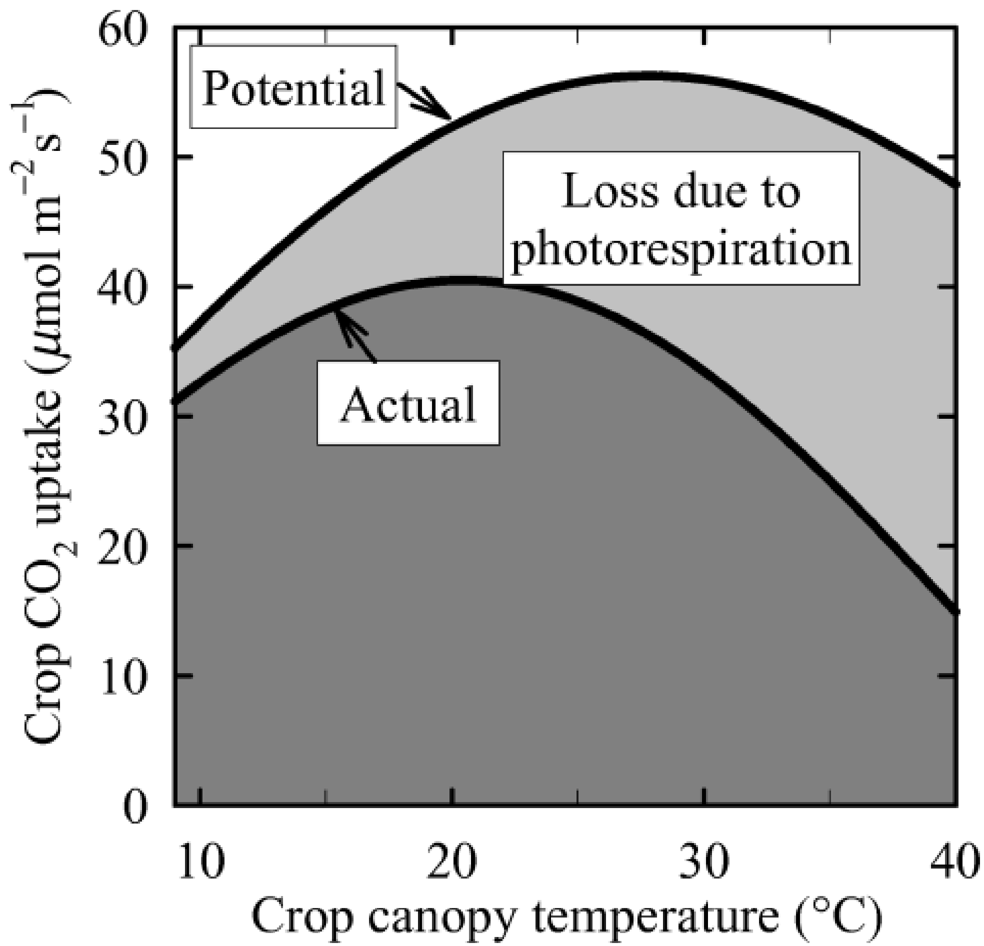


Actual and potential rates of crop canopy photosynthesis v temperature



Long *et al* 2006. *Plant, Cell & Environment* **29**, 315-330

Theme 1: Increasing Photosynthetic Capacity and Efficiency

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- SP1.1: Phenotypic selection for photosynthetic capacity and efficiency
- SP1.2: Phenotypic selection for ear photosynthesis
- SP1.3: Optimising and Modelling canopy photosynthesis and duration
- SP1.4: Chloroplast CO_2 pumps
- SP1.5 : Increasing RuBP Regeneration
- SP1.6: Improving the thermal stability of Rubisco activase
- SP1.7: Replacement of LS Rubisco

Theme 1: Increasing photosynthetic capacity and efficiency

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Matthew Reynolds — CIMMYT

Martin Parry
Huw Jones — ROTHAMSTED RESEARCH

Tony Condon
Robert Furbank — CSIRO

Xin-Guang Zhu — SIBS

Susanne von Caemmerer
Murray Badger
John Evans — ANU, THE AUSTRALIAN NATIONAL UNIVERSITY

Anil Day — MANCHESTER 1824

John Foulkes
Eric Murchie — The University of Nottingham

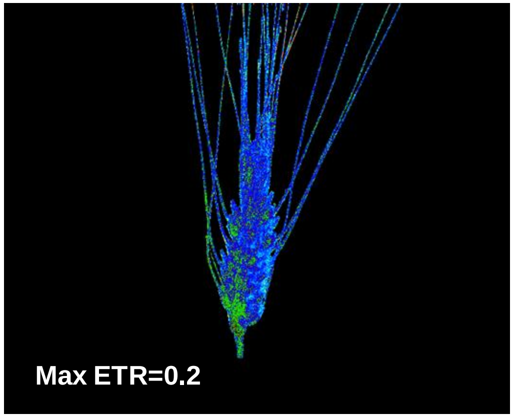
Christine Raines — University of Essex

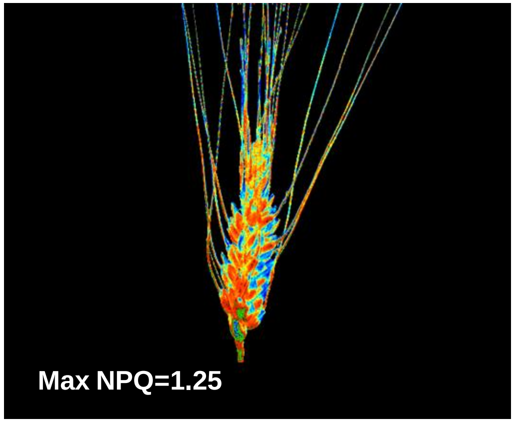
Jose Luis Araus — UNIVERSITAT DE BARCELONA

SP1.1 Screening for Photosynthetic Efficiency and Capacity

- Grind and find screen for kinetic properties (slow and laborious)
- Sequence based screen
- In vivo physiology screen for kinetic properties
  - Tractable using gas exchange screen, canopy T and chlorophyll fluorescence for thousands of lines
  - Can use the subset of germplasm for grind and find
  - Could also find other useful traits (NUE, stomatal response)

Ear Photosynthesis





- **Photosynthesis of glumes and awns can provide up 30% of grain carbon**
- **Considerable genetic variation**
- **Can be screened for with chl fluorescence**
- **Has not been selected for**

Theme 1: Increasing Photosynthetic Capacity and Efficiency

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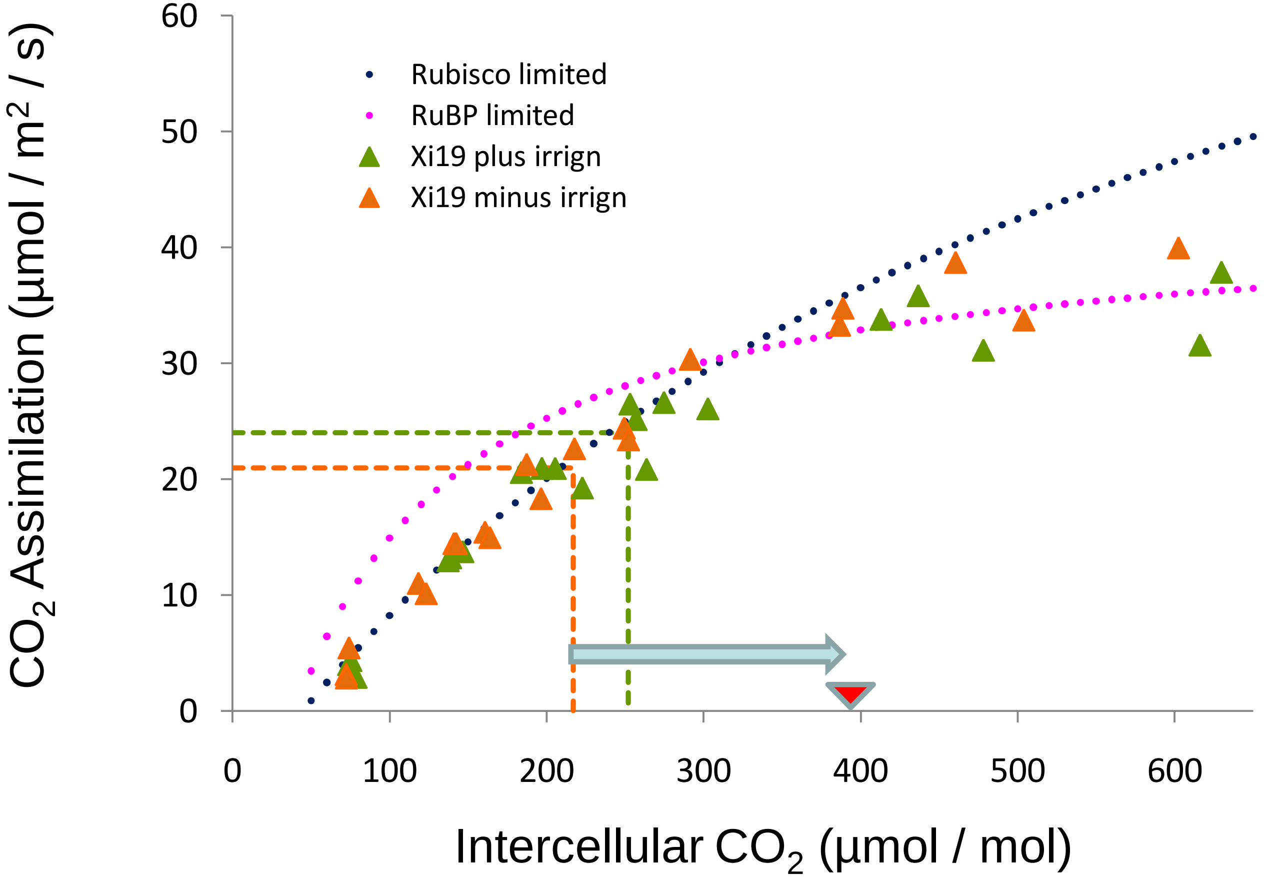
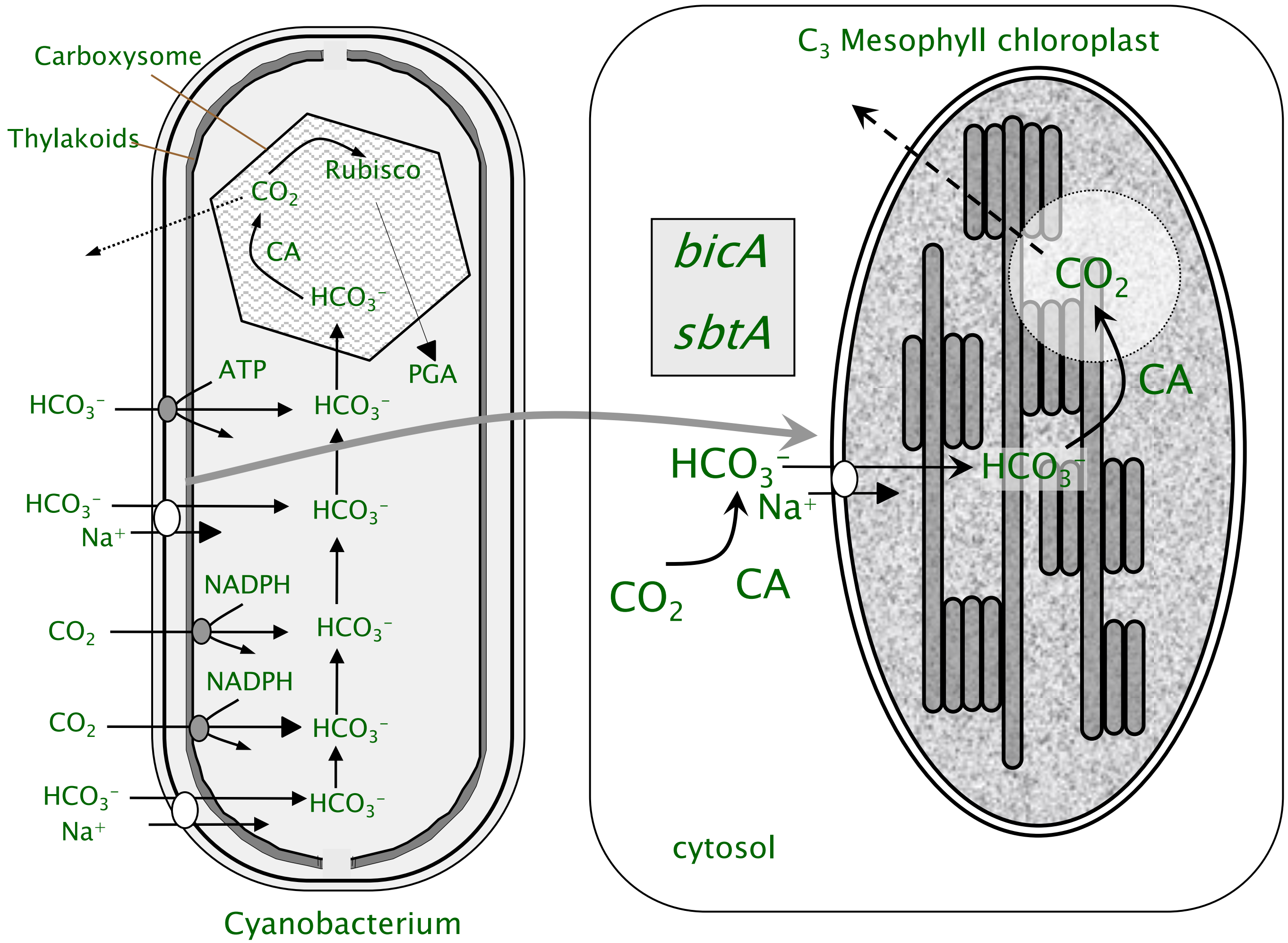
CREATE NOVEL GERMPLASM BY TRANSGENIC APPROACHES

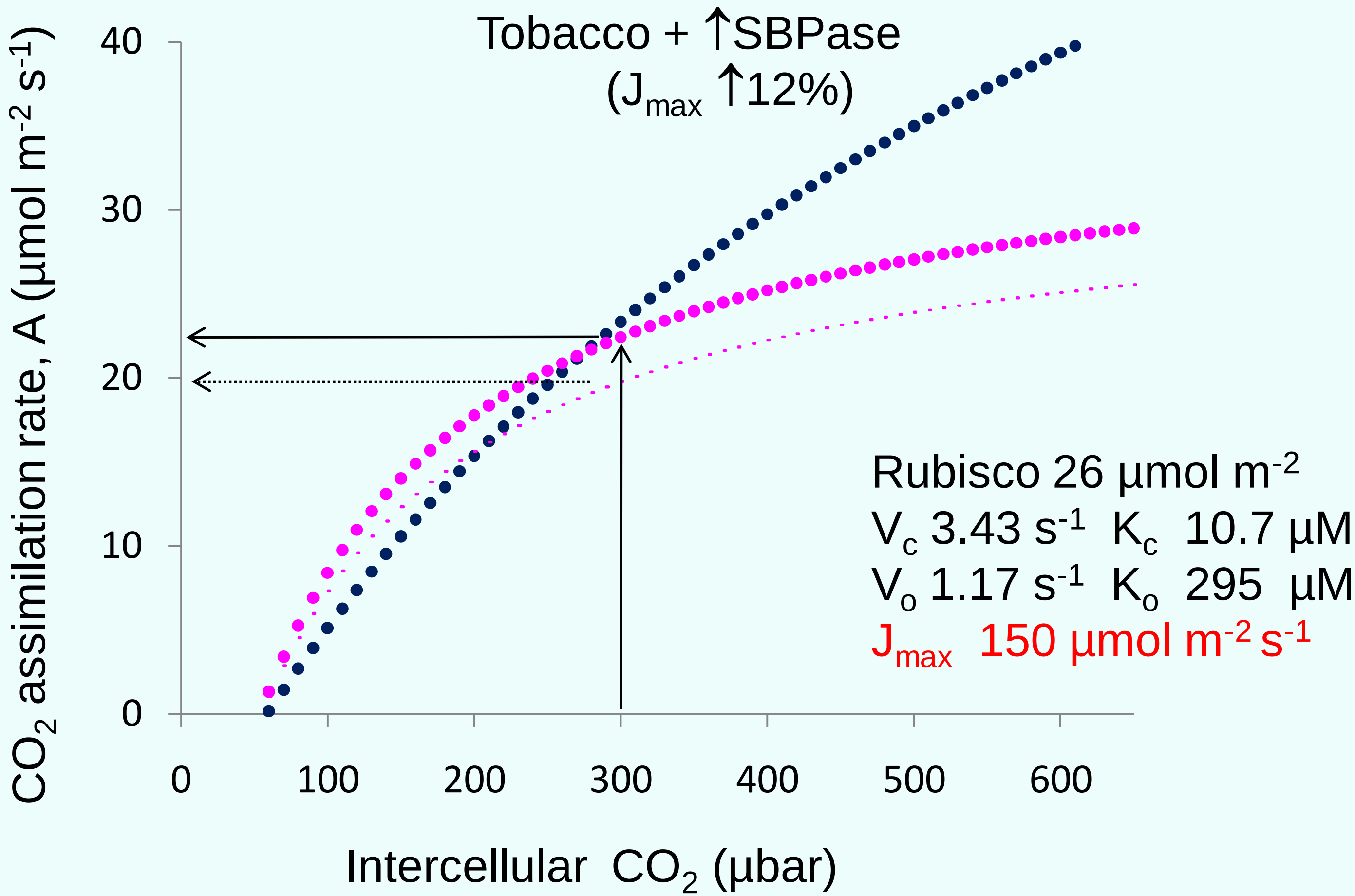
ACi for Field Grown Xi19 ± Irrigation



Carbon concentration



Increasing RuBP Regeneration

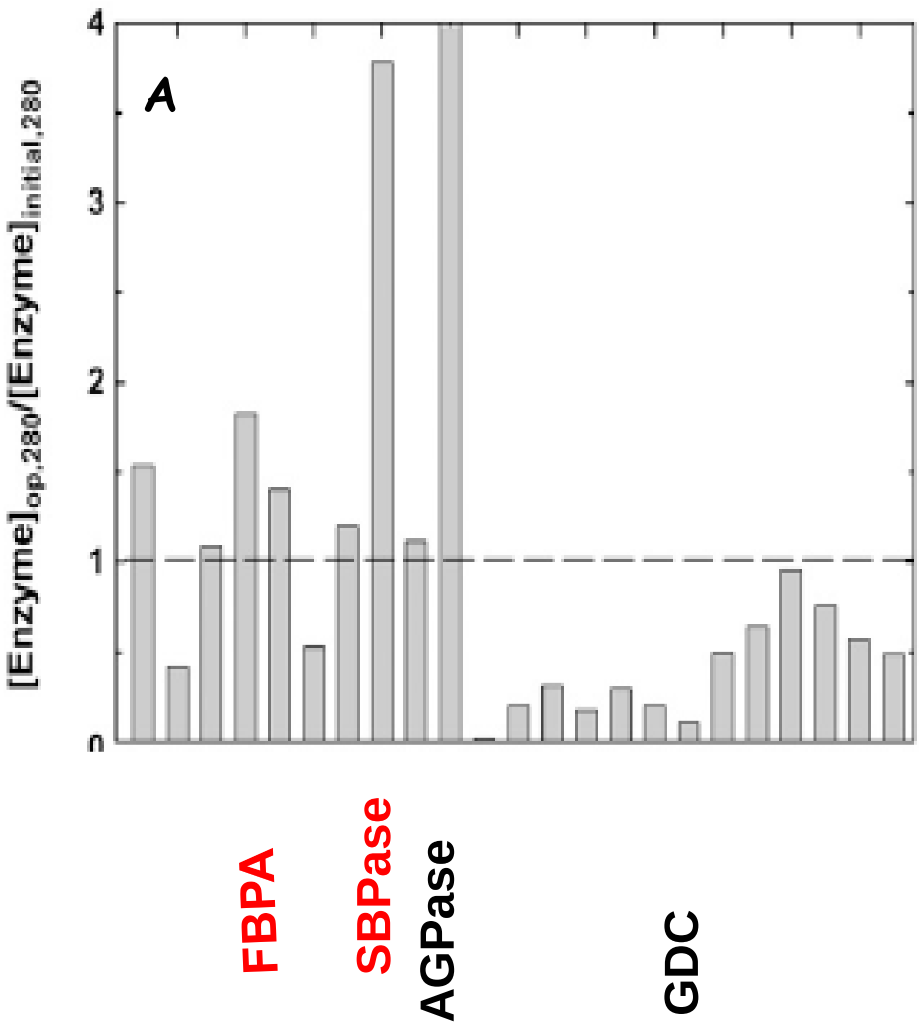


(V_c,V_o,K_c, K_o from Whitney *et al*, 1999)

Increased SBPase acitivity

Growth stimulated in 7wk tobacco plants in GH

Optimal Allocation or Resources



Zhu *et al*., 2007 *Plant Physiology* **145**: 513-526

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Rubisco Forays

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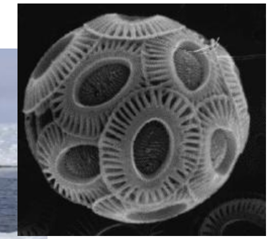
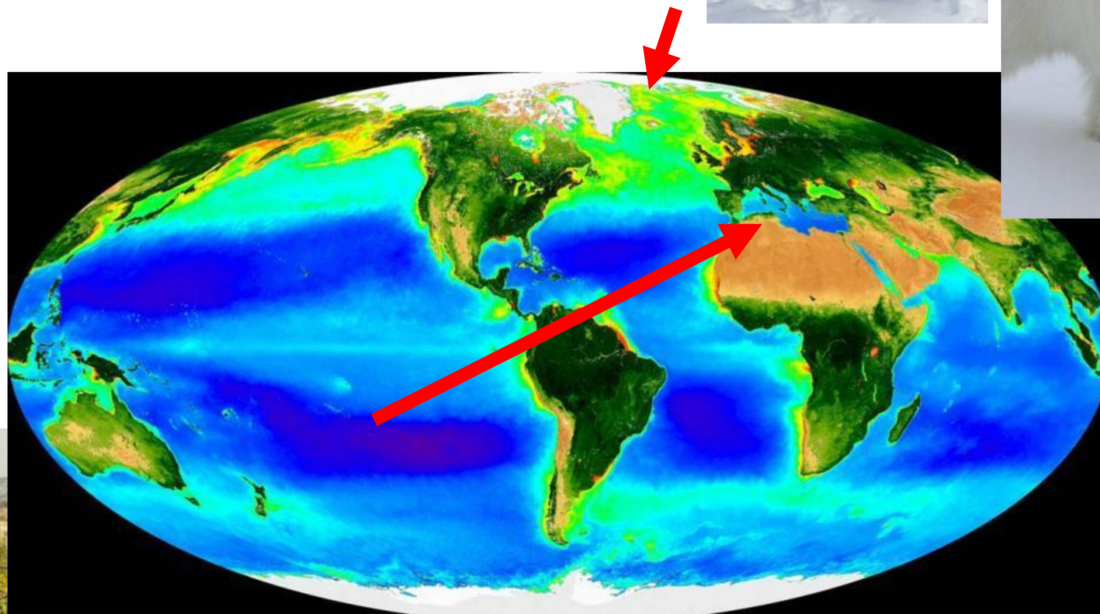
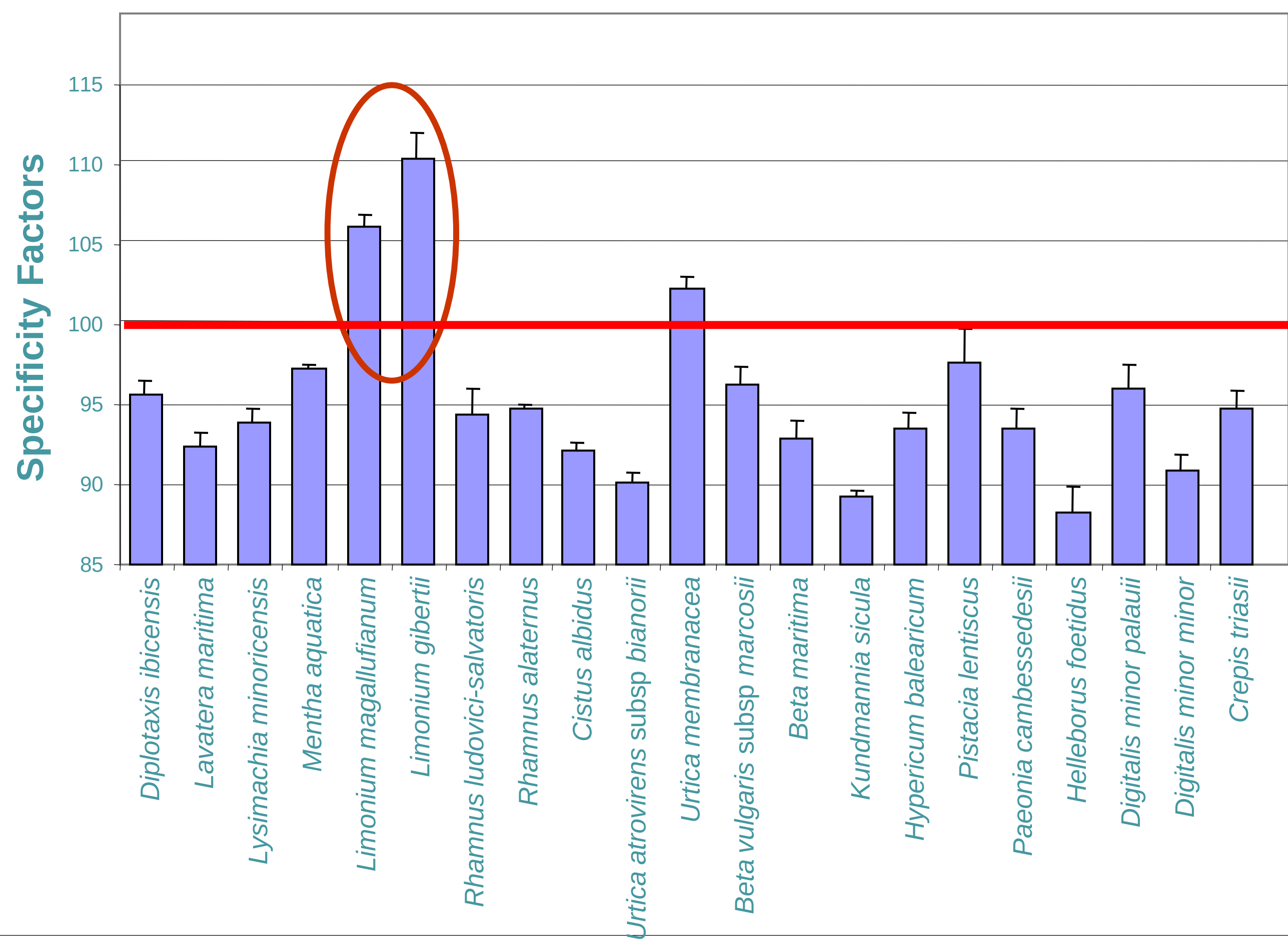
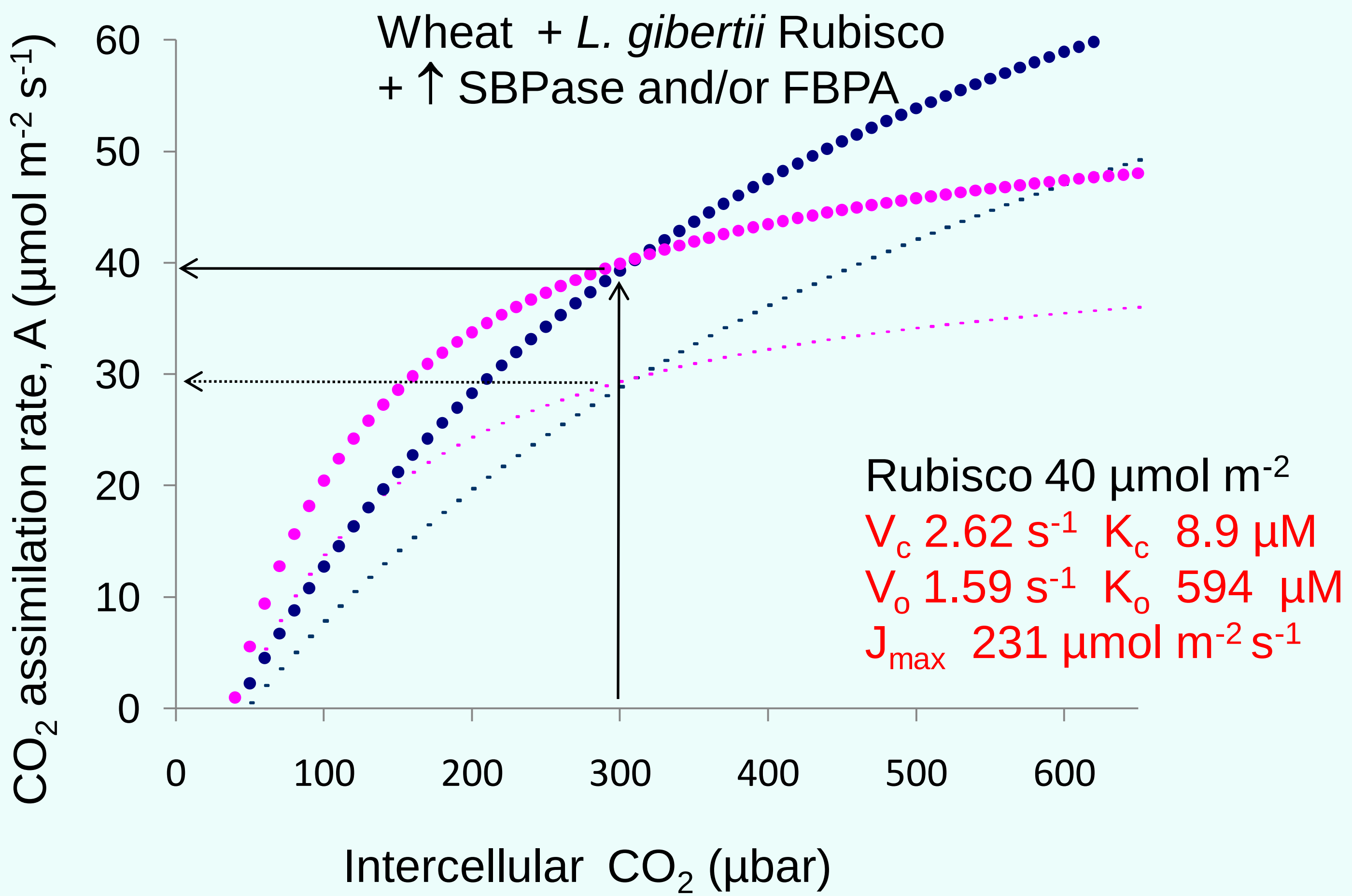




Specificity factor for Rubisco at 25ºC



Rubisco Engineering



(V_c,V_o,K_c, K_o from Galmes *et al*, Rothamsted Research)

Expectations

Modification	Predicted Increase (%)	Time scale (years)
Mine existing germplasm	5-20	<5
Short-circuiting photorespiration	0-5	5
Increased mesophyll conductance	5-10	5
Increased RuBP regeneration	0-10	5
Exploiting existing species variation in Rubisco	0-20	12
Exploiting existing species variation in Rubisco	10-35	15
and increased RuBP regeneration		
Optimized Rubisco regulation	5-20	10
CO_2 pump	0-30	10
CO_2 pump with Kranz anatomy	50	20
Rubisco without oxygenase and high K_{cat}	100	20

Theme 2: Optimizing HI

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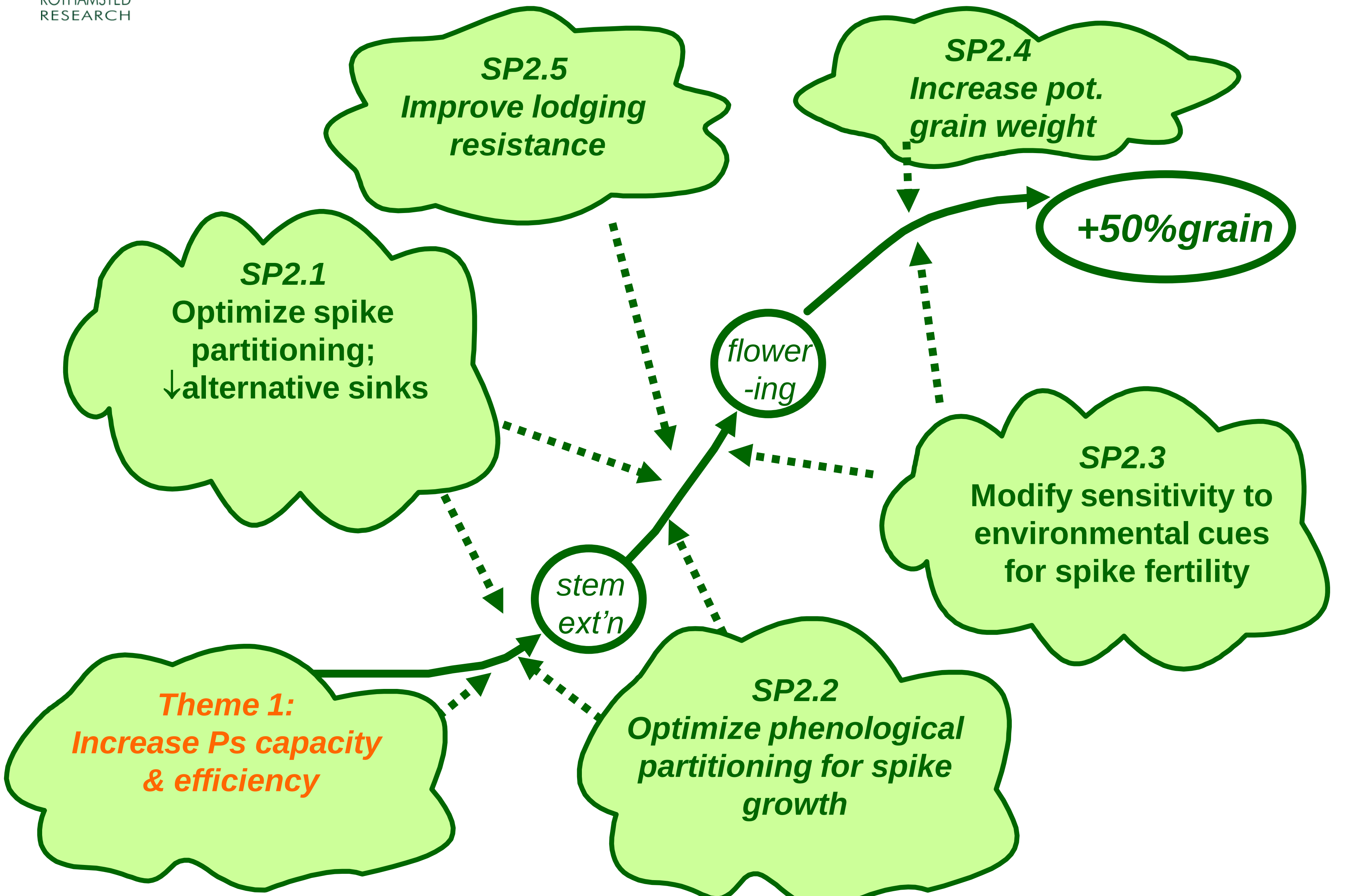

Theme 2: Optimising partitioning to grain yield while maintaining lodging resistance

Gustavo Slafer
I Romagosa

Simon Berry
Bill Angus

D Miralles

F Gonzalez   INTA

WJ Davis

Pete Berry

Chris Baker
Mark Sterling

Penny Rifkin

John Foulkes

Structural failure (lodging) must be avoided in heavier yielding plants

- Lodging already a persistent phenomenon in wheat (Easson *et al.*, 1993)
- Reduces yield by as much as 80% and reduces grain quality
- Heavier yielding crops will require stronger plants
- Genetic improvement of stems and crown roots will be needed
- Trade-offs between partitioning to spikes versus stems/roots must be optimized

(Berry *et al.*, 2007)

Traits for lodging proof ideotype

	Lodging-proof crop	Best current variety
Root plate spread (mm)	57	46
Stem wall width (mm)	0.65	0.75
Stem diameter (mm)	4.25	3.84
Material strength (Mpa)	43	34
Stem & root biomass (t/ha)	8.8	7.7

Theme 3: Breeding to accumulate yield potential traits

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- SP 3.1: Trait and marker based breeding to combine traits
- SP3.2: Wide crossing to enhance photosynthetic capacity
- SP 3.3: Genomic selection to increase breeding efficiency
- SP3.4: Germplasm testing and delivery to LDCs

Theme 3: Trait and gene deployment with trait based breeding

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Ian King — The University of Nottingham

Rowan Sage — Ecology & Evolutionary Biology, University of Toronto

Ron Phillips
Perry Gustavson — University of Minnesota, Driven to Discover℠

Peter Langridge — ACPFG Australian Centre for Plant Functional Genomics Pty Ltd

Simon Griffiths — John Innes Centre

Integrating research and breeding

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Basic research platforms: complementary traits

Sequential research platforms: germplasm

RUE
C4 like traits
•Carbon concentrating mechanisms

RUE
Rubisco
•RuBP regeneratio n
•Thermaly stable Rubisco activase
•Rubisco engineering

RUE
Canopy PS
•Identify range of optimal canopy structures/ N profiles
•Estimate contribution of spikes to net PS
•Develop rapid screens for PS

HI
Optimize partitionin g to yield
•Identify optimal make up of Ppd, Vrn, Eps to maximize spike fertility
•Identify basis of 'conservative' kernel abortion
•Optimize grain weight potential

Lodging resistance
•Identify lodging resistance traits for high yield scenarios
•Optimize tradeoff between lodging resistance and spike fertility

Define traits/markers

Explore genetic resources

Pre-breeding: Wide crossing: amphiploids, synthetics, transformation
Test alternate physiological models to harmonize traits

Breeding: Introgress high yield traits into elite backgrounds
Multilocation testing to determine impact in diverse target regions
Deploy new genotypes to breeding programs worldwide

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Funding

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GRDC Grains Research & Development Corporation

Australian Government
Australian Centre for International Agricultural Research

The World Bank

USAID FROM THE AMERICAN PEOPLE

bbsrc biotechnology and biological sciences research council

Expected outputs of WYC

- 10-50% increased biomass (10-25 years)
- Harvest index >/= 0.5
- Structural failure improbable in 90% of years
- Simultaneous expression of all characteristics in most major wheat agro-ecosystems.
- Spill-over effects into marginal environments

Know More – JXB Publications

Matthew Reynolds, David Bonnett, Scott C. Chapman, Robert T Furbank, Yann Manès, Diane E Mather & Martin AJ Parry. (2010) Raising yield potential of wheat. I. Overview of a consortium approach and breeding strategies *J. Exp. Bot. doi:10.1093/jxb/erq311*

Martin AJ Parry, Matthew Reynolds, Michael E Salvucci, Christine Raines, P John Andralojc, Xin-Guang Zhu, G Dean Price, Anthony G Condon & Robert T Furbank (2010) Raising yield potential of wheat. II. Increasing photosynthetic capacity and efficiency *J. Exp. Bot. doi:10.1093/jxb/erq304*

M. John Foulkes, Gustavo A. Slafer, William J. Davies, Pete. M. Berry, Roger Sylvester-Bradley, Pierre Martre, Daniel F. Calderini, Simon Griffiths & Matthew P. Reynolds (2010) Raising yield potential of wheat. III. Optimizing partitioning to grain while maintaining lodging resistance *J. Exp. Bot. doi:10.1093/jxb/erq300*